

# Plants are multicellular organisms with specialized structures.

## Key Concepts

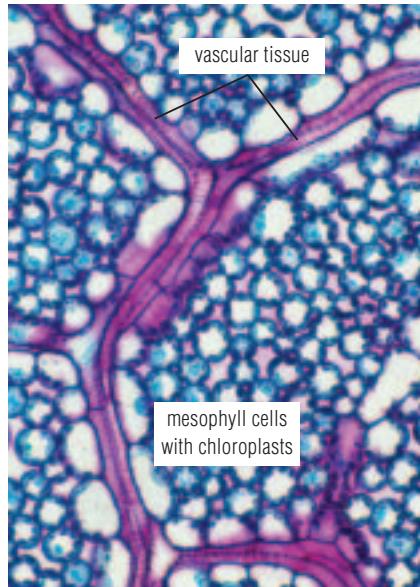
In this section, you will learn about the following key concepts:

- use of explanatory and visual models in science
- cell specialization in multicellular organisms; i.e., plants
- mechanisms of transport, gas exchange, and environmental response in multicellular organisms; i.e., plants

## Learning Outcomes

When you have completed this section, you will be able to:

- explain why, when a single-celled organism or colony of single-celled organisms reaches a certain size, it requires a multicellular level of organization, and relate this to the specialization of cells, tissues, and systems in plants
- describe how the cells of the leaf system have a variety of specialized structures and functions
- explain and investigate the gas exchange system in plants
- explain and investigate the transport system in plants
- explain and investigate phototropism and gravitropism as examples of control systems in plants
- trace the development of theories of phototropism and gravitropism



**FIGURE C3.1** This section of a lilac leaf cut parallel to the surface shows cells in tissues specialized for different functions within the leaf. Light micrograph (approx.  $\times 250$ )

**I**magine being stranded on a desert island with a group of your family and friends. You would have two choices. You could look out only for yourself and be responsible for all of your own needs, including food and shelter, or you could work with the others on the island, giving each person a particular responsibility for the community. In the second scenario, everything does not depend on one person alone, and each person works for the good of the whole group. On the other hand, individuals lose some of their independence by specializing in one area and not having control over all aspects of their survival.

These ideas can in some ways be applied to cells. The protists you examined in the pond water exist as single-celled individuals, each responsible for carrying out all life processes. Each cell maintains an efficient surface area to volume ratio in order to sustain life. If a cell becomes too large to function efficiently, it will usually divide to produce two new cells. Both cells are now able to flourish. However, many of the prepared slides and photomicrographs you have viewed show material from multicellular organisms. You are a multicellular organism. So are a tree, an onion, an earthworm, and an elephant. Multicellular organisms are made of many cells (your body has trillions), but the cells are not all alike. When an organism grows in size, it is essential that some specialization occurs to deal with different functions. In a multicellular organism, different types of cells facilitate the movement of nutrients, gases, essential molecules, and wastes.

The understanding of life processes at the microscopic level can also be applied to a multicellular organism. This section will focus on plants as examples of multicellular organisms with specialized structures at the cellular, tissue, and system levels. Figure C3.1 shows a variety of tissues present in a leaf.

# C 3.1 Cells, Tissues, and Systems

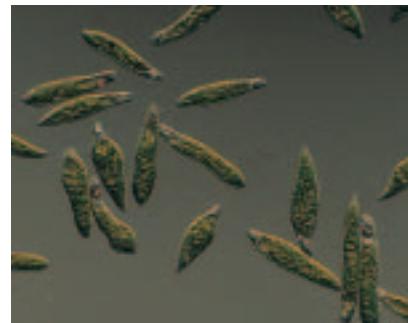
Organisms, small or large, unicellular or multicellular, such as those shown in Figure C3.2, can survive if both their needs and the challenges of their environments are met. To survive, the *Euglena* depends on the normal function of a single cell, while the lodgepole pine depends on the normal function and interaction of countless cells that make up its large structure. There are advantages and disadvantages to having a large structure that depends on countless single cells. These are listed below.

- Division of labour—when cells are specialized for one particular function, they can perform it more effectively and efficiently. It is like having the luxury to concentrate on just one task and so doing it perfectly. Contrast this situation with the single-celled organism, which must be a multi-tasker, performing all necessary functions at the same time.
- Size—the surface area to volume ratio and the related rate of diffusion restricts the size of a unicellular organism. In multicellular organisms, internal transport systems allow efficient exchange of materials. These transport systems permit the organism to grow to a larger size.
- Interdependence of cells—the life of a multicellular organism does not depend on a single cell. When a single-celled organism dies, that is the end of that particular organism. If one cell of a multicellular organism dies, it does not kill the entire organism. There is a cost, however. If one type of cell functions abnormally, for example becomes cancerous, it is possible that as the cancer increases, the whole organism will suffer.

## Plant Structure

Plants are multicellular organisms; they can be regarded as living systems made up of many parts, each performing its own important function. As plants grow and increase in size, the cells begin to have specialized functions. Although every cell contains the same genetic information, individual cells perform particular jobs within the organism. Groups of cells performing the same function together are called **tissues**. Tissues contributing to the same function form **organs** which are part of a **system**. The plant has two organ systems, as shown in Figures C3.3 and C3.4. The **shoot system** is everything that is above ground; it includes the stem, leaves, buds, flowers, and fruits. It also includes **tubers** (swollen stems that store food, for example potatoes) even though they are under the ground. The **root system** is everything underground, but also includes aerial roots even though they are above ground.

Cells divide for the growth of new tissue and repair of damaged tissue. Mitosis is the process of cell division that allows growth and repair; in this process, one cell literally divides into two cells.



(a) Unicellular *Euglena*. Light micrograph (approx.  $\times 250$ )

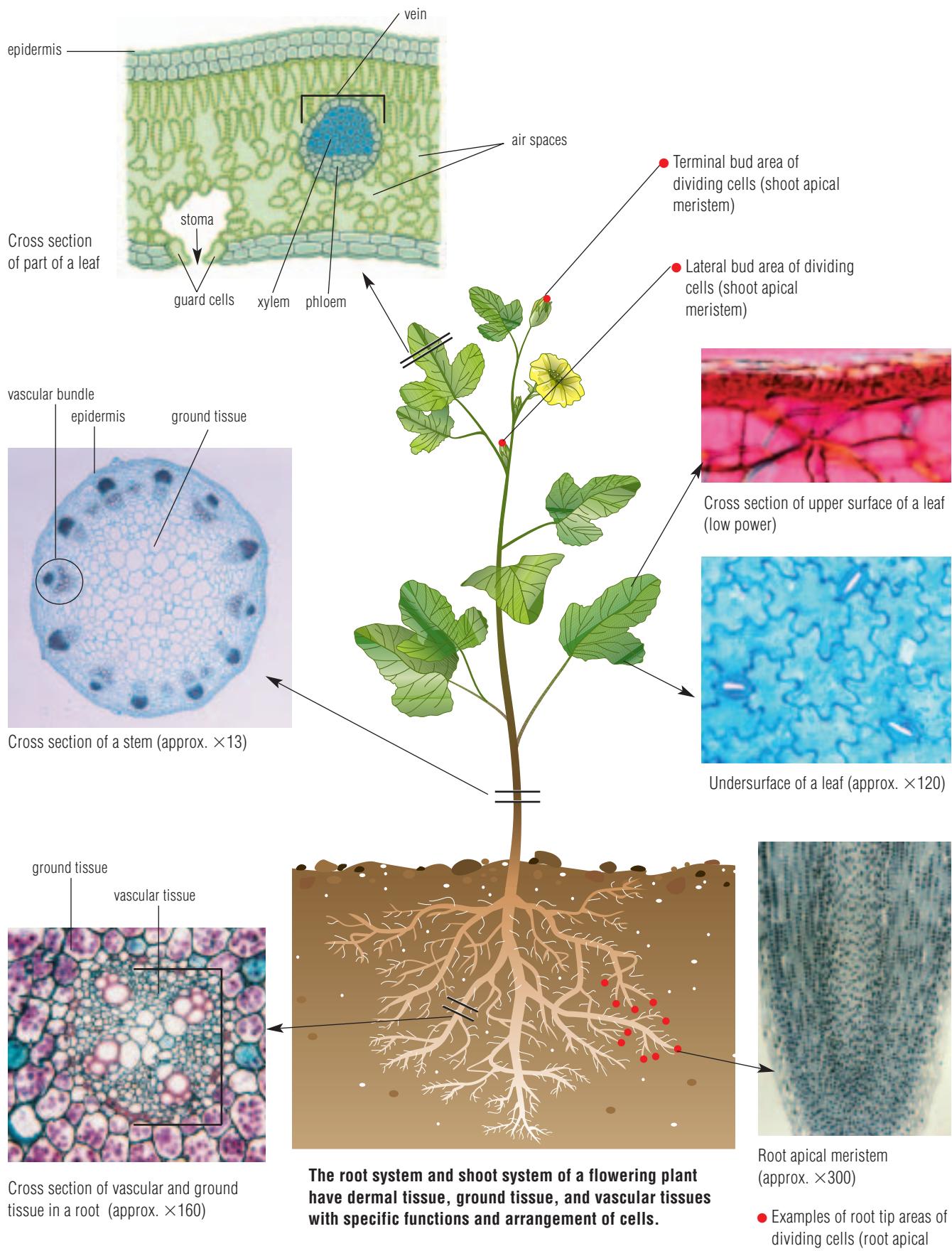


(b) Very large lodgepole pines

**FIGURE C3.2** The challenges of survival can be solved in very different ways.

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Multicellular animals, like plants, are also composed of tissues made up of many cells performing the same task. In humans, we refer to nervous tissue, muscle tissue, and connective tissue, for instance. Tissues grouped together to perform similar tasks form organs. The skin is the largest organ of your body. Organs work together to form a system. The heart, arteries, veins, and capillaries are made of different tissues, but all are connected and depend on the efficient functioning of each cell to form the circulatory system.



**FIGURE C3.3** The shoot system and root system in a plant

Cell division does not occur at the same rate throughout the organism. In plants, increase in size results from cell division in particular growth areas called **meristems**. Different meristems produce root tissue and shoot tissue (Figure C3.3). The process is one of constantly creating new building blocks that add to one another almost endlessly. The giant Douglas fir tree is an example of the meristems doing their work continually over a long period of time to produce an enormous organism.

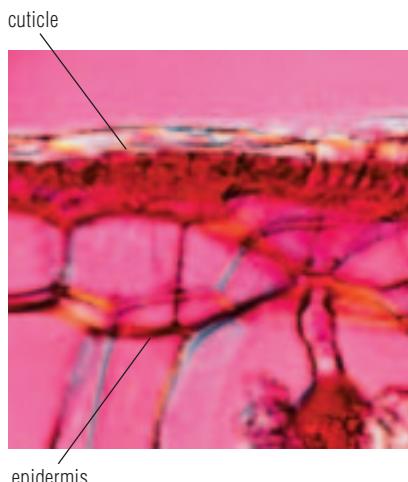
The root and shoot systems are made up of tissues specialized for different activities such as gas exchange, transport of materials, and photosynthesis. In their turn, the tissues are made up of individual, specialized cells that each contribute to the function of the tissue. There are three main types of plant tissues. Figure C3.3 shows the relationship of these tissues in different parts of a flowering plant.

**Dermal tissue** or **epidermis** is the outer layer of cells that covers all **herbaceous** (non-woody) plants. This tissue is generally one cell-layer thick and is responsible for the exchange of matter and gases into and out of the plant. In woody plants, the epidermis of the stem is replaced by cork and bark during the secondary growth stage of development. The dermal tissue of the shoot system organs, the leaves and stem, is primarily involved in gas exchange of carbon dioxide and oxygen. This dermal tissue also protects the plant from disease. The cells of the leaves and stem secrete a waxy substance called the **cuticle** that resists attack from micro-organisms and helps to reduce water loss from the plant. The cuticle is shown in Figure C3.5(a). Dermal tissue of the root system organs is responsible for the uptake of water and mineral salts from the soil.

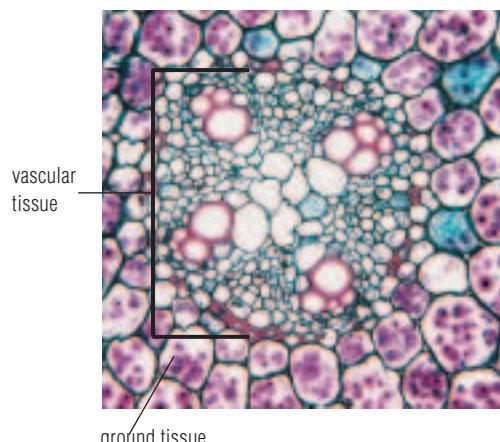
**Ground tissue** makes up the majority of the plant and is found as a layer beneath the epidermis. Ground tissue has several important functions. In the stem, it provides strength and support to the plant; in the roots, it is involved in food and water storage; and in the leaves, it is the location where photosynthesis occurs. The cells of the ground tissue are loosely packed together and the air spaces between cells allow gases to diffuse rapidly through the ground tissue. Figure C3.5(b) shows the ground tissue in a root.



**FIGURE C3.4** The shoot system and root system in the developing bean plant

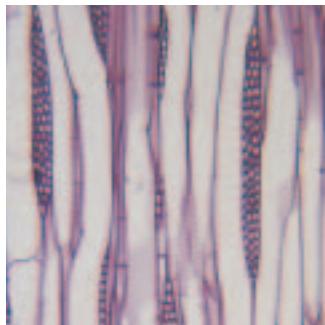


(a) The cuticle protects the surface of the leaf.  
(LM polarized light; low power)

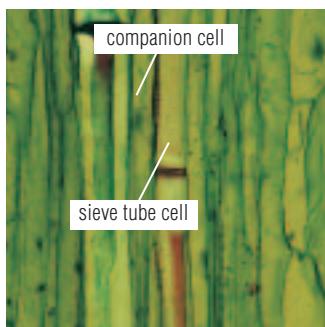


(b) Ground tissue in the root is important for storage. Light micrograph (approx.  $\times 200$ )

**FIGURE C3.5** Tissues in leaf and root



(a) The xylem of the stem is made up of parallel tubes. Light micrograph (approx.  $\times 200$ )

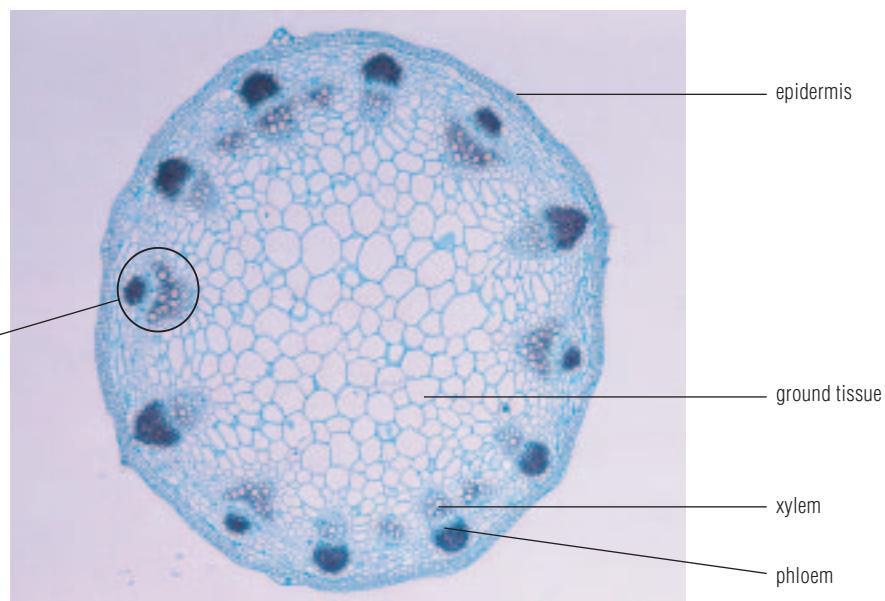


(b) The phloem tissue of the stem is made up of sieve tube cells with associated companion cells. Light micrograph (approx.  $\times 200$ )

**Vascular tissue** is responsible for the transport of materials throughout the plant. **Xylem tissue** moves water and dissolved minerals from the roots up the stem to the leaves where these substances are used in photosynthesis. Xylem vessels are thick-walled tubes of varying diameters, the thickening being the result of cellulose and possibly lignin being deposited in the cell wall. As the cylindrical cells mature, they fuse together and the walls at each end become perforated. As a result, the contents of the cytoplasm break down, and the cells die, leaving the non-living cell walls attached together like a long straw. Imagine stacking paper towel rolls one on top of the other and taping them together to form one long tube. These non-living ducts are responsible for the movement of water and minerals up the stem. Figure C3.6 shows the composition of the xylem and phloem.

**Phloem tissue** transports sucrose and other dissolved sugars from the leaves to other parts of the plant. The phloem is formed from individual long **sieve tube cells**, which have perforated end walls, through which the cytoplasm extends. The sieve tubes form continuous ducts. Imagine the same tower of stacked paper tubes, except this time there are pinholes along the length of the rolls, and in between every two tubes there is a piece of gauze to allow the flow of materials from one roll to another. The sieve tube cells remain alive, but lose their nuclei. In many plants, sieve tube cells are connected to small, nucleated **companion cells** that appear to direct their activities. The sugars transported by the phloem are used to provide energy for cellular processes such as protein manufacture, or are converted into cellulose. Cellulose forms fibrous structures for strength and support and may become associated with lignin in the formation of wood. Some of the transported sugars may be stored as starch in roots (carrots, sweet potatoes), stems (ginger, potatoes), or leaves (green onions, rhubarb). Figure C3.7 shows the organization of the three tissue types in the stem of herbaceous plants.

**FIGURE C3.6** Vascular tissues



**FIGURE C3.7** Cross section of a herbaceous stem, showing the tissue types as seen through the light microscope (approx.  $\times 20$ )

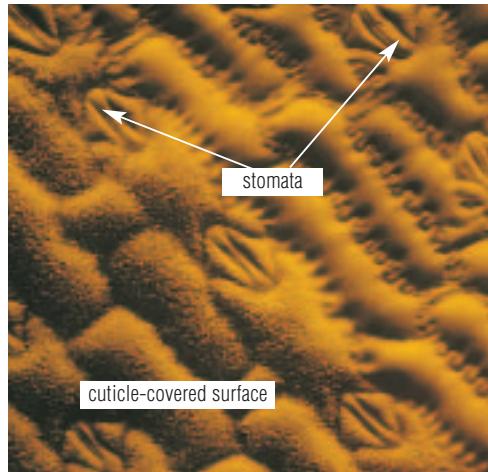
## Specialization in Plant Cells

Cells that are no longer part of the meristem show the characteristics of only certain parts of their genetic code. Cells become specialized for a particular function and produce only the products needed for that function. The following are some examples of specialization in plants.

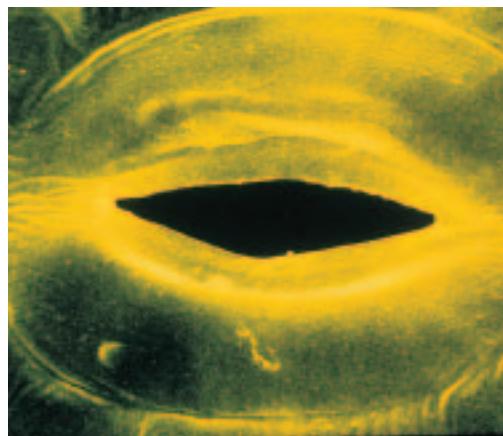
- (i) Cells that become part of the root system and are responsible for the absorption of water and minerals from the soil, produce tiny hair-like projections called **root hairs** (Figure C3.8(a)). The root hairs increase the surface area for absorption of water—more cell surface is exposed to the soil and therefore the amount of water that is able to enter the root by osmosis is maximized. You may have noticed these tiny root hairs when you pull a carrot or radish from the garden.
- (ii) Dermal cells of the shoot system produce cuticle (Figure 3.8(b)) to protect the cells from water loss.



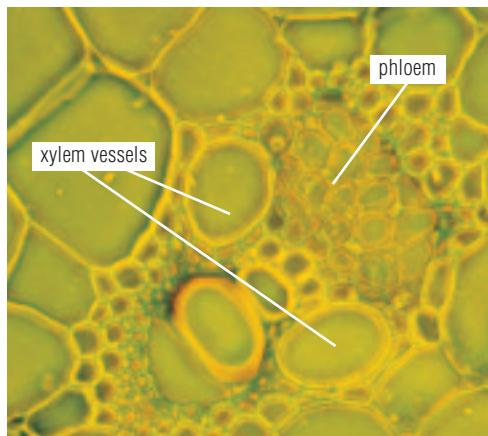
(a) Cells of the root showing root hairs as seen through the light microscope (approx.  $\times 100$ )



(b) Scanning electron micrograph of cells in the upper epidermis of a leaf showing the cuticle and stomata (approx.  $\times 1800$ )



(c) A scanning electron micrograph of a stoma (approx.  $\times 12000$ )



(d) Cells in a vascular bundle seen through the light microscope (approx.  $\times 200$ )

**FIGURE C3.8** Types of specialized plant cells

## reSEARCH

Investigate the different functions of the ground tissue in plants. What specializations make these functions possible?

Begin your search at

 [www.pearsoned.ca/  
school/science10](http://www.pearsoned.ca/school/science10)

- (iii) The lower epidermal surface of leaves develops specific cells, called **guard cells**, that form tiny pores called **stomata** for gas exchange (Figures C3.8(b) and C3.8(c)). The guard cells are the only cells in the epidermis that contain chloroplasts. The upper epidermis usually has fewer stomata than the lower.
- (iv) Cells that become part of the xylem in the vascular tissue specialize to be able to conduct water and to allow the transport of water to adjacent cells. These cells die during differentiation of the xylem and therefore are empty inside (Figure C3.8(d)). They form long tubes that behave almost like straws to move water and dissolved salts throughout the plant. For example, the long fibres in celery are the vascular tissue of the plant.

### C3.1 Check and Reflect

#### Knowledge

1. Define the following terms:
  - a) unicellular
  - b) multicellular
  - c) tissues
  - d) organ
  - e) organ systems
  - f) meristems
2. Name and describe each of the organ systems in plants. Draw a diagram to illustrate your description.
3. Prepare a chart to outline the advantages and disadvantages of being multicellular.

#### Applications

4. In plants, as in other multicellular organisms, cells specialize to perform specific functions. List four examples of ways that specialization provides for the life processes of the plant.
5. Explain why plant stems and leaves have a layer of cuticle but plant roots do not.
6. Draw a diagram of a tomato or bean plant to show all of the tissue types described in section C3.1. Describe how each of these tissues contributes to the overall function of the plant.

#### Extensions

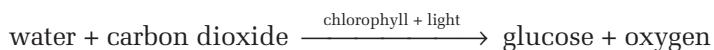
7. Humans have cultivated and bred plants for centuries to provide food, fibre, fuel, and medicine. For many years, as a result of plant research, crop yields have increased. Recently, however, yields are less able to keep up with demand, as fertile land is lost and the population increases. Plant researchers must find ways to meet the challenges of production and to fight famine worldwide while attempting to maintain a sustainable environment and prevent any further decline in biodiversity.
  - a) Suggest how research into plant structure and the relationships between different plant tissue types may aid scientists in meeting the challenge of increasing crop yields in a sustainable environment.
  - b) Plants share similar physical structures and tissue relationships, as outlined in this section, but they also show a huge diversity. How can understanding both the similarities and differences assist scientists in their research?
8. There is growing concern about climate change and the degradation of the environment and about ways that human activity may be important to these changes. In what ways could research into plant structures and their possible uses for food and fibre address these issues?

## C 3.2 The Leaf and Photosynthesis

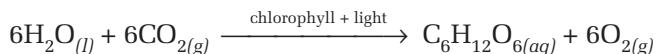
The leaf is a collection of tissues whose main purpose is to carry out or support the process of photosynthesis. Within the overall requirements, each type of tissue—dermal, ground, and vascular—has a particular purpose and function. The survival of the whole organism requires every cell and tissue to perform its function.

### The Chloroplast: A Unique Plant Organelle

Unlike animal cells, many plant cells have organelles called chloroplasts that contain the green pigment, chlorophyll. Chloroplasts are easily identified in the cytoplasm by their colour. Cells containing chloroplasts are found in the ground tissue of leaves and sometimes in stems. Chloroplasts are very important to the functioning of the cell and the organism. These organelles are where the plant carries out photosynthesis, a chemical process in which carbon dioxide from the air and water from the soil, in the presence of light energy, produce glucose and oxygen. **Photosynthesis** means putting together with light (“photo” = light; “synthesis” = putting together). The word equation for photosynthesis is:



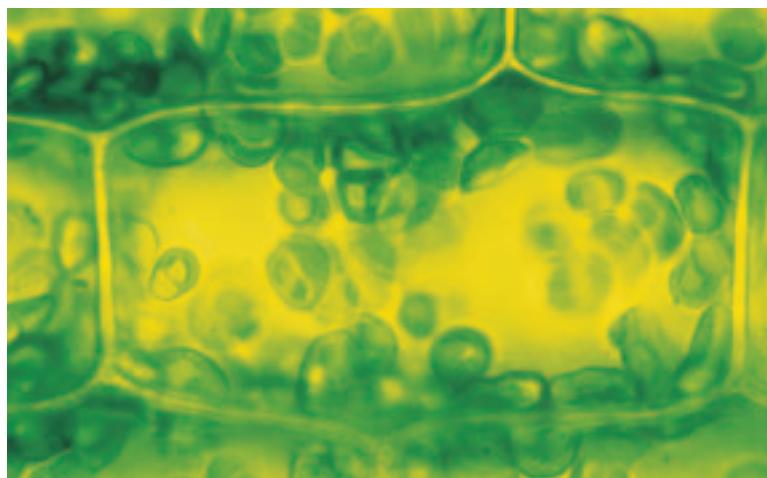
The balanced chemical equation for photosynthesis is:



In photosynthesis, the light energy is absorbed by the chlorophyll and converted into chemical energy that is stored in the molecules of glucose for future use in fuelling cellular processes. Light and chlorophyll are not considered to be reactants or products. Figure C3.9 shows chloroplasts as seen through the light microscope.

#### info BIT

10<sup>21</sup> J is the annual global net amount of energy produced by photosynthesis.



**FIGURE C3.9** Chloroplasts in plant cells seen through the light microscope (approx.  $\times 3000$ )

## Required Skills

- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

## Counting Chloroplasts

In this activity, you will be using an aquatic plant called *Elodea canadensis* which is native to Western Canada. *Elodea* grows in ponds, anchored to the pond floor. It has a tube-like stem with many small, thin leaves growing from it. Similar South American species are used in aquariums. Small fish eat the leaves, but primarily the many leaves of the plant provide protection and shelter.

### The Question

How many chloroplasts are present in a typical cell of an *Elodea* leaf?



### Materials and Equipment

- compound light microscope
- glass slides and coverslips
- droppers
- forceps
- Petri dishes
- Elodea canadensis*, Java Moss, or other aquatic plants

**CAUTION: Wash your hands at the end of the lab activity.**

### Procedure

- 1 Transfer some water from the aquarium where the plants are kept into a Petri dish. Using the forceps, transfer a section of the plant into the water you collected.
- 2 Using the forceps, carefully remove one small, thin leaf from the plant and place it on a clean glass slide.
- 3 Make a wet mount of the leaf. Be careful not to include air bubbles under the coverslip.
- 4 Examine the slide through the microscope using the low-power objective. Find an area where the cells are clearly visible. Switch to high power so that you can see organelles in the cell. The round, green organelles are chloroplasts. The leaf is two cell-layers thick. Use the fine adjustment knob to focus up and down through the layers.

- 5 Draw what you see in the field of view. Set up a data table and record the number of chloroplasts present in each of 10 cells. Find the mean number of chloroplasts per cell.
- 6 Compare the number of chloroplasts in cells near the edge of the leaf and in cells in the middle of the leaf.
- 7 Draw one chloroplast. Label your diagrams with the name of the plant and the total magnification used.
- 8 Estimate the actual size of the chloroplast by comparing it with the diameter of the field of view, using the technique you learned in Activity C2.
- 9 Try to distinguish the cell wall in these chloroplast-packed cells. The central vacuole is also present but it is difficult to see because it is transparent and filled with water.
- 10 Continue to observe the chloroplasts. What do you notice about their position in the cell? Are they moving or stationary?

### Analyzing and Interpreting

1. What was the mean number of chloroplasts in the cells you observed? Were there significant differences in the number of chloroplasts in cells near the edge of the leaf compared with the middle of the leaf? Provide a possible explanation of your observation.
2. Describe the movement of the chloroplasts in the cell. This movement is often termed cytoplasmic streaming. What is its function? Are the chloroplasts of the same cell moving in the same direction? Are the chloroplasts of all the cells in the field of view all moving in the same direction?

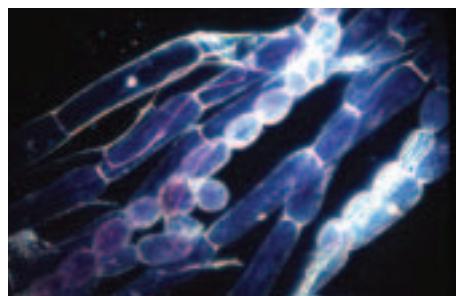
### Forming Conclusions

3. Write a statement to answer the question posed at the beginning of the inquiry, based on your observations.

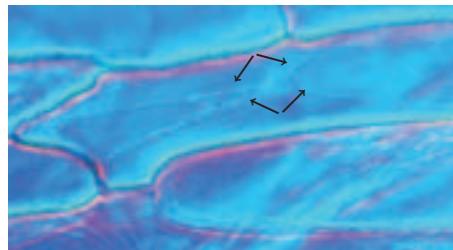
### Applying and Connecting

4. Plant cells have three structures that are absent from animal cells. Suggest reasons why animals do not need these structures, but plants do.

Movement of chloroplasts within cells has given indirect evidence that the cytoplasm behaves like a fluid. This type of movement of the cytoplasm and its contents is termed cytoplasmic streaming. It is a mechanism that circulates materials and speeds up their distribution within the cell. Robert Brown, who discovered the nucleus, also discovered and demonstrated cytoplasmic flow in plant cells. His experiments with *Tradescantia* pioneered the study of the flow of matter within the living cell. Figure C3.10(a) shows hair cells in stamens of *Tradescantia*, observed in a repeat of Brown's experiments. Figure C3.10(b) shows strands of cytoplasm in onion cells undergoing cytoplasmic streaming.



(a) Robert Brown discovered cytoplasmic streaming in *Tradescantia* stamen hairs, here viewed through his microscope. (approx.  $\times 40$ )



(b) A section through onion cells showing cytoplasmic streaming seen through the light microscope. Arrows indicate strands of cytoplasm. (approx.  $\times 600$ )

**FIGURE C3.10** Cytoplasmic streaming

## Gas Production in Plants

There are two important reactions that take place in plants and produce gases as products. These reactions are in many ways the opposite of each other. Photosynthesis occurs in the chloroplasts of plants in the presence of light energy and carbon dioxide, producing glucose and oxygen. The light energy is converted to chemical energy stored in the bonds within the glucose molecules.

To obtain energy to fuel the cell's activities, a second general reaction is needed. This process is called **cellular respiration**, and is a set of reactions in which bonds are broken and other bonds formed in new compounds, with the result that energy is released.

Cellular respiration begins in the cytoplasm but is completed in the mitochondria by way of a series of reactions that release energy and produce carbon dioxide and water. The word equation for cellular respiration is:



The chemical equation for cellular respiration is:



These reactions produce the energy needed by the cell to carry out its life processes. Cellular respiration using the same chemical reactions is also carried out in animal cells to provide energy for the life processes. However, plant tissues respire at a much lower rate than animal tissues, and the  $\text{CO}_2$  produced during cellular respiration is not an obvious product during the day, when photosynthesis is going on.

In the dark, photosynthesis cannot take place. The plant stops manufacturing food but the process of cellular respiration continues and any carbon dioxide that is produced is released.

## Required Skills

- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

## Evidence of Carbon Dioxide Production

Gas production differs in plants and animals. During photosynthesis, plants use carbon dioxide and produce oxygen. During cellular respiration, both plants and animals produce carbon dioxide. When aquatic organisms produce carbon dioxide, it dissolves to produce a weak acid called carbonic acid. Carbon dioxide production can be detected by using an indicator solution called bromothymol blue (BTB), which responds to changes in acidity. As carbonic acid is produced, the BTB in solution will change from blue to green (low concentration of acid) to yellow (higher concentration of acid). This colour change gives indirect evidence of the production of carbon dioxide. In this investigation you will consider the effect of light on carbon dioxide production in systems containing plants and animals.

### The Question

Does light have an effect on carbon dioxide production by plants and animals?

### The Hypothesis

Predict whether the presence or absence of light will affect carbon dioxide production in an aquatic plant and an aquatic animal.

### Materials and Equipment



10 glass screw-cap vials	grease pencil or marker
4 sprigs of an aquatic plant (e.g., <i>Elodea canadensis</i> or Java moss), of the same size and with the same number of leaves	NaOH solution, 0.01 mol/L 
4–6 aquarium snails	Area of the lab that will be lit for 24 hours (i.e., under grow lamps)
plastic straws	Area of the lab that will be darkened (i.e., inside closed cabinet)
water	
bromothymol blue indicator solution in a dropper bottle	

**CAUTION: Wear gloves for this activity. Bromothymol blue stains skin. Wash your hands at the end of the lab activity. Sodium hydroxide ( $\text{NaOH}_{(aq)}$ ) is corrosive. Avoid contact with skin. If  $\text{NaOH}$  gets on your skin, flush immediately under running water and inform your teacher.**

### Procedure

- 1 Number the vials 1–10. Add water to each vial, allowing approximately 1.5 cm of air space.
- 2 Add an equal number of drops of BTB to each vial so that the colour of the solution remains consistently blue. If the solution turns green, carefully add 0.01 mol/L  $\text{NaOH}_{(aq)}$ , one drop at a time, until the solution becomes and stays blue.
- 3 Loosely secure the caps on vials 1 and 2 and set aside.
- 4 Add carbon dioxide to vials 3, 4, 7, and 8 by blowing through a straw until the solution turns yellow. Loosely secure the caps. Set vials 3 and 4 aside.
- 5 Place a sprig of the aquatic plant, with cut end upward, in vials 5, 6, 7, and 8 and loosely secure the caps. Set aside.
- 6 Place one snail in each of vials 9 and 10 and loosely secure the caps. Set aside. The contents of the vials are shown in the table on page 307.
- 7 Prepare a data table in which to record observations for each of the 10 vials. Remember to give your table a title. List the contents of each vial, the colour of the solution in each vial, and whether the vial is placed in the light or dark. Leave space for your observations before and after the experiment.
- 8 Place vials 1, 3, 5, 7, and 9 in a lighted area for 24 hours (Figure C3.11).
- 9 Place vials 2, 4, 6, 8, and 10 in a completely dark area for 24 hours (Figure C3.11).
- 10 Record the colour of the solution in each vial, after 24 hours of dark or light treatment, in your data table.

### Contents of Vials 1–10

Vial Number	Vial Identification
1	water + BTB (control)
2	water + BTB (control)
3	water + BTB + CO <sub>2</sub> (control)
4	water + BTB + CO <sub>2</sub> (control)
5	water + BTB + plant
6	water + BTB + plant
7	water + BTB + CO <sub>2</sub> + plant
8	water + BTB + CO <sub>2</sub> + plant
9	water + BTB + snail
10	water + BTB + snail

### Analyzing and Interpreting

1. Describe the colour observed in each vial. Use labelled diagrams to illustrate your observations.
2. Explain the need for vials 1, 2, 3, and 4 as controls in this experiment.

3. What colour change occurs in bromothymol blue solution if carbon dioxide is dissolved in the solution? Explain why.

4. Based on the colour changes observed, which of the vials showed the presence of carbon dioxide?

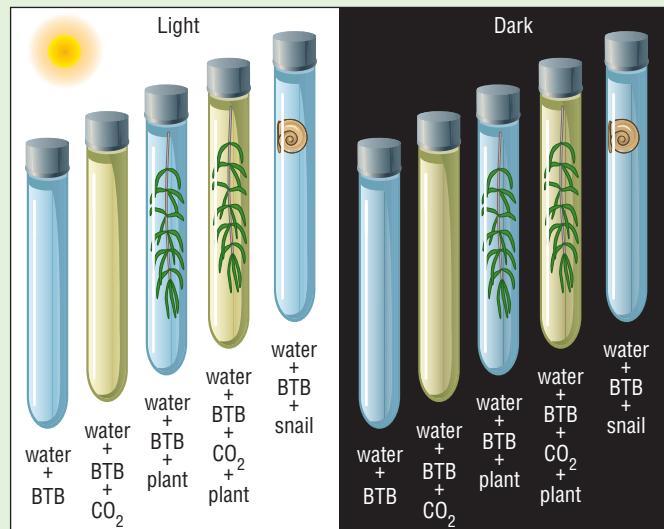
### Forming Conclusions

5. From the results of your experiment, what can you infer about the production of carbon dioxide by plants and by animals in the light and the dark?

6. Write a statement to answer the question posed.

### Extending

7. Suggest a possible experimental procedure to determine whether the carbon dioxide produced by the snail could be used by the aquatic plant in conditions of light or dark.
8. If your lab is equipped with oxygen-sensing probes, propose an experimental procedure using the aquatic plant, to record the production of oxygen under conditions of light and dark.
9. How might the techniques used in this inquiry be applied to a study investigating the effects of changes in carbon dioxide concentration on plants?



**FIGURE C3.11** Set-up of vials for light and dark treatments

## reSEARCH

The complex process of photosynthesis has been investigated through cell research based on the understanding of how molecules function. Find out more about cellular research on plants. Begin your search at



[www.pearsoned.ca/  
school/science10](http://www.pearsoned.ca/school/science10)

Experiments to investigate gas production in organisms under various conditions may focus on the formation of the product or on the consumption of the reactants. For example, in a study of photosynthesis students may observe oxygen production by counting the bubbles of oxygen produced by an aquatic plant, or by measuring the volume of water displaced by the oxygen gas produced. Alternatively, photosynthesis may be studied by measuring the amount of carbon dioxide consumed in the process. Cellular respiration in plants or animals may be studied as the amount of oxygen consumed in the reaction or the amount of carbon dioxide produced as a product of the reaction. Oxygen-sensing probe ware can provide a measure of the change in the gas volume over the course of an experiment.

## C3.2 Check and Reflect

### Knowledge

1. Describe the process of photosynthesis. Include the word equation and the chemical equation.
2. What essential role does chlorophyll play in photosynthesis?
3. Explain the differences in activity of plant cells in the dark and in the sunlight.

### Applications

4. Why is it useful to know the actual size of a cell or organelle?
5. *The chloroplasts and the mitochondria in a cell have opposite functions.* Agree or disagree with this statement. Explain your answer.
6. An important part of Alberta's economy is related to the oil and gas industry. Oil and gas, used to power our vehicles, heat our homes, and cook our meals, can be traced back to pre-historic plants and animals that died and were buried under layers of rock for millions of years. In fact, almost everything we eat or use can be traced back to plants because of their ability to take energy from the Sun to produce sugar and starch.

Trace each of the following items back to plants. Draw a schematic to show the

number of “degrees of separation” for each item.

- a) cotton shirt
- b) ham and cheese sandwich
- c) coal (the main source of electricity in Alberta)
- d) an item of your own choosing—see if you can get “6 degrees of separation”

### Extensions

7. What would happen in the process of photosynthesis if:
  - a) more carbon dioxide was available?
  - b) the light intensity was increased?
8. Heat energy was not identified in the photosynthesis equation, yet gardeners will tell you that the warmth of a greenhouse is advantageous in producing healthy and faster growing plants. How do you explain this?
9. Have you ever been lazing on an air mattress on a lake or pool? Without using any energy of your own, you are able to drift around quite easily. Relate this experience to the movement of the chloroplasts in the cell. What are the chloroplasts drifting on? Design and build a model to mimic the fluidity of the cytoplasm and the movement of organelles within the cell.

## C 3.3 The Leaf Tissues and Gas Exchange

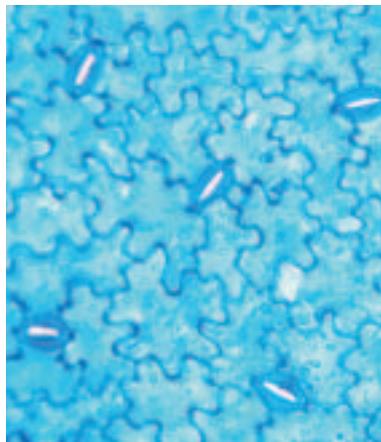
Air can enter cells by passive diffusion. However, it would take a long time to get the needed volume of air into a plant that way, especially with the cuticle covering the surface of most of the plant. To solve this problem, the leaf has specialized cells to maximize its ability to exchange gases. There are also other specialized cells that function to provide the reactants and remove the products of the leaf's cellular activities.

### Dermal Tissue

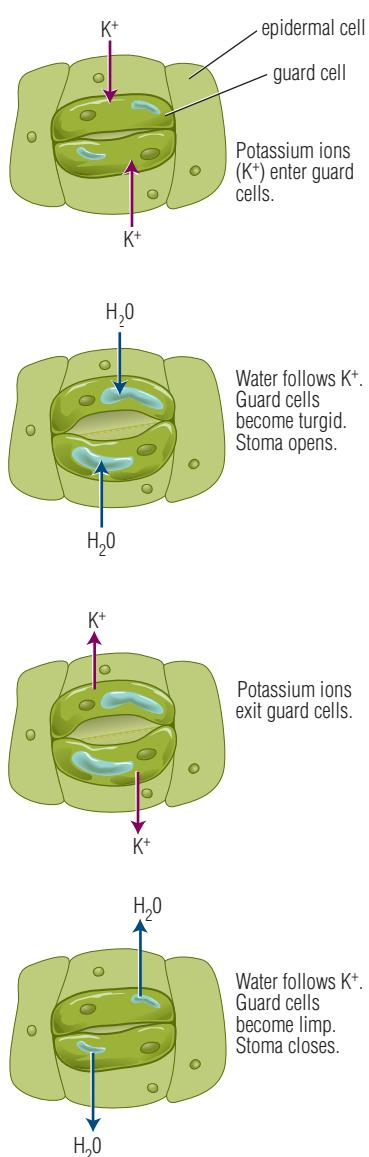
The epidermis on both the top and underside of the leaf is clear and very thin. Specialized cells called guard cells form tiny openings or pores called stomata that allow gas exchange to happen easily. The stomata regulate the movement of gases. They open into air chambers that connect with the cells of the ground tissue. Carbon dioxide and oxygen can therefore enter and leave the leaf by diffusion at any time. The direction of the movement of these gases depends on their concentration gradients. The majority of stomata are found in the lower epidermis on the underside of the leaf. Figure C3.12 shows the arrangement of stomata in a leaf.

It would not be efficient to have the stomata open all of the time. The guard cells that surround the stomata control whether they are open or closed. The guard cells are kidney bean-shaped and, depending on conditions, swell up to open the stomata, or shrink away so that the stomata are closed. Light striking the leaf stimulates the guard cells to accumulate potassium ions by active transport. As a result, the number of particles present in the guard cells increases, water enters by osmosis, and the guard cells swell up under increased turgor pressure. The outer walls of the guard cells are thinner than the inner walls, so the cell under pressure bulges outward and is drawn into a crescent shape. In this way, the stoma opens.

Guard cells function to allow materials in and out when necessary, but also to protect the leaves from losing too much water through open stomata. Because all gases must dissolve in a film of water to pass across cell membranes, a film of water is always on the surface of cells. This means that water is continually being lost from the plant by evaporation through the stomata. In conditions where water is not readily available, the guard cells become limp and this closes the stomata. A model of the mechanism for opening and closing the stomata is shown in Figure C3.13. The process of water vapour leaving the leaf through the stomata is called **transpiration**. Without the control system operated by the guard cells, transpiration could dangerously dehydrate a plant.



**FIGURE C3.12** Stomata and guard cells in a leaf seen through the light microscope (approx.  $\times 120$ )



**FIGURE C3.13** The opening and closing of the stomata are controlled by changes in the cell contents, followed by movement of water.

## Required Skills

- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

## Analyzing Stomata

Transpiration is the movement of water vapour out of the leaf through the stomata. By controlling the opening and closing of stomata, the guard cells provide the control system necessary to reduce water loss from the plant. In the first part of this activity you will observe plants, which your teacher provides, to obtain indirect evidence of this process of controlling water loss. In the second part of the activity, you will use prepared slides to make an analysis of the numbers of stomata present in different plants. You will use the data from both parts of the activity to form a conclusion.

### The Question

What effects do environmental factors have on the number and appearance of stomata and on their ability to monitor the process of transpiration?

### The Hypothesis

Using what you know about the role of stomata in plants, state what you think would happen to the number and appearance of stomata in conditions that are (a) dry or (b) humid.

### Materials and Equipment

- 3 potted plants covered with clear plastic bags (e.g., cactus, jade, geranium)
- prepared slides of leaf epidermis (e.g., cactus, geranium, pine needles, *Elodea*)
- compound light microscope

**CAUTION: Observe proper technique with the microscope and slides to ensure safe handling of equipment.**

### Procedure

- 1 Examine the three potted plants provided by your teacher. These plants have been covered with clear plastic bags for a few days, as shown in Figure C3.14.
- 2 As a large group, discuss the differences between the plants. Record your observations in a table of class results.
- 3 Examine each of the prepared slides of leaf epidermis provided by your teacher. Using the low-power objective, examine the slide and draw and label what you see. Include the name of the plant and the total magnification.
- 4 Move to the medium- and high-power objectives. Observe epidermal cells, presence or absence of stomata, cell nuclei, and chloroplasts.
- 5 Set up a data table in your notebook. Count and record the number of stomata in your field of view. Draw and label what you see, and include the name of the plant and the total magnification. Repeat this step twice more for each slide, observing cells in two other fields of view.
- 6 Using a spreadsheet or graphing calculator, enter the number of stomata per unit area found in each plant. Include the average of the three fields of view for each plant. Generate a bar graph to allow a comparison of the plants.



**FIGURE C3.14** Set-up of plants for observing transpiration activity in step 1

## Analyzing and Interpreting

1. Compare the results of covering the three different plants with clear plastic bags.
2. Based on your knowledge of transpiration, explain your observations.
3. Describe the shape of the epidermal cells you observed in each of the prepared slides. Are there any differences in cell shape among the different plants?
4. In which cells of the epidermis did you find chloroplasts?

## Forming Conclusions

5. Based on your observations and graphed results, develop a statement describing the relationship between the environment (high or low humidity) and the number of stomata found in plants adapted to each environment.
6. What is the relationship between the number of stomata and the amount of transpiration?

## Applying and Connecting

7. Why do plants show a variation in the stomata density rather than in the size of the stomata? Consider the function of the stomata in your answer.

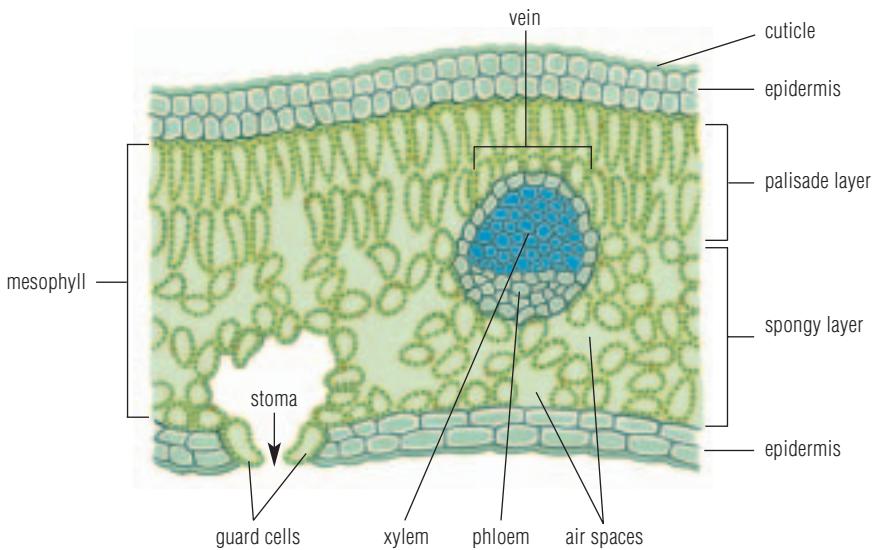
### ***Sensitivity of Stomata***

The number and appearance of stomata in the epidermis are sensitive to environmental conditions. Since plants must regulate the loss of water through transpiration, those growing in hot, dry climates with low humidity have adapted to having fewer stomata. In places where humidity is high, water loss is not a problem and plants may have many stomata. Similarly, if carbon dioxide is in short supply, stomata may be open to the maximum to obtain whatever carbon dioxide is available. If there is a normal level of carbon dioxide available for photosynthesis, the stomata will be less stressed.

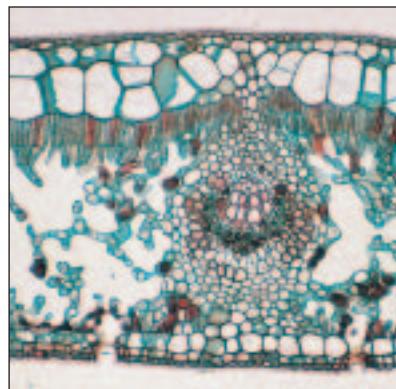
### **Ground Tissue**

Between the upper epidermis and the lower epidermis of the leaf are specialized ground tissues called **mesophyll**. There are two very different types of mesophyll tissues. The **palisade tissue cells** are found just below the upper epidermis. They are long, rigid, rectangular cells that are tightly packed together and arranged so that a large number of cells are exposed to the Sun's rays. The palisade tissue cells are responsible for photosynthesis, so as you would expect, there are many chloroplasts in this layer of tissue. These cells require carbon dioxide as a reactant during photosynthesis and produce oxygen as one of the products.

Between the palisade tissue cells and the lower epidermis are loosely packed, irregularly shaped, less rigid cells making up the **spongy mesophyll tissue**. The increased space between these cells allows for the primary function of the spongy mesophyll tissue: gas exchange by diffusion throughout the leaf. The mesophyll cells will move oxygen toward the stomata for expulsion from the plant and will move carbon dioxide from the air toward the palisade cells. Figure C3.15 shows a cross section through a leaf.



(a) A cross section of a leaf showing the component tissue types



(b) Light micrograph of a leaf in cross section (approx.  $\times 70$ )

**FIGURE C3.15** Tissue relationships in a leaf

### Activity C15

## QuickLab

### Airtight

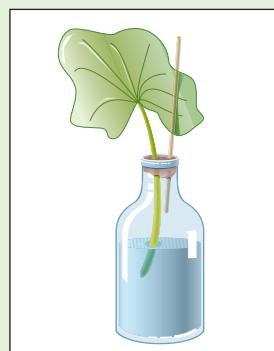
#### Purpose

To observe the ability of leaves to exchange gases

#### Materials and Equipment

narrow-necked glass bottle	leaves similar to geranium leaves
straws	modelling clay

water



**FIGURE C3.16**

Set-up of Quicklab experiment step 4

#### Procedure

- For this activity, you will work in pairs. Partially fill the bottle with water as shown in Figure C3.16.
- Cut a fresh leaf from the plant your teacher provides. Be sure to have a long stem attached to the leaf.
- Wrap modelling clay around the stem, close to the leaf. Place the stem into the bottle so that the end of the stem is submerged in the water. Wrap the clay around the bottle opening to seal.
- Poke a small hole in the clay and insert the straw. The straw should not touch the water. Re-seal the clay around the straw so that there is no air leakage. Figure C3.16 shows the experimental set-up.

- Suck on the straw to pull the air out of the bottle. If you are having difficulty, check for holes in the straw or air leaks around the clay seal.
- Have a partner observe what is happening in the water. Record the observations.
- Exchange the straw for a clean one and re-seal the opening. Switch roles with your partner. Record your observations.

#### Questions

- Describe what happened when air was withdrawn from the bottle.
- Offer an explanation for your observations.

The process of diffusion is very efficient in plants because of the air spaces present in the spongy mesophyll of the leaf and within the stem. Air diffuses through the stomata and into air spaces in the leaf, through the intercellular spaces and down the stem. Activity C15 shows evidence of this airflow. As air is sucked out of the bottle, a vacuum is created and air from outside enters the bottle through the leaf and stem.

## Vascular Tissue

The vascular tissue provides the leaf with the water needed for transpiration and for photosynthesis, and also removes the sugars formed in photosynthesis. If you observe a leaf, you will see a network of ribs running through it. These ribs, called leaf veins, contain the vascular tissue of the leaf. The xylem and phloem tissues are bunched together like a handful of straws in a **vascular bundle**. The xylem transports water, necessary for photosynthesis, and dissolved salts from the roots to the leaf. The phloem transports the sugar manufactured in photosynthesis to the rest of the plant. The vascular bundles are direct extensions of the vascular bundles of the stem. They branch into finer veins within the spongy mesophyll. Examine Figure C3.15 again to see the relationships between all the tissues in the leaf.

The next time you are drinking from a juice box with a tight-fitting straw, try poking a small hole in the top across from your straw. It is much easier to drink the juice by allowing air to enter the box as you are drawing it out through the straw—a lot quieter too!

## Gas Exchange in Plants

In plants, all gas exchange occurs by diffusion. There are no organs specifically concerned with gas exchange. Diffusion of gases occurs through air spaces and then across cell membranes. In the leaf, the stomata, regulated by guard cells, allow for more efficient intake of gases and therefore for more rapid diffusion of carbon dioxide into the palisade and spongy mesophyll cells. Diffusion of oxygen out of the leaf is also maximized by the air spaces in the ground tissue and the presence of stomata in the epidermis.

The leaf is not the only place where gas exchange occurs. You may have noticed what appear to be blisters or slashes on the stems of trees and herbaceous plants, as shown in Figure C3.17. These are natural openings. They are pores along woody stems and mature roots, the result of a split in the secondary outer tissues that replace the epidermis. These pores are called **lenticels** and, like the stomata, provide a pathway for gas exchange. Like the stomata, the lenticels also provide an opening for transpiration to occur.



**FIGURE C3.17** Photograph of lenticels as seen on the inner surface of a piece of birch bark. Lenticels allow gas exchange to and from the inner parts of the tree trunk. (approx.  $\times 4$ )

## reSEARCH

What are some of the ways in which knowledge about leaf structure is used in agriculture and horticulture? Begin your search at

 [www.pearsoned.ca/school/science10](http://www.pearsoned.ca/school/science10)

### C3.3 Check and Reflect

#### Knowledge

1. Draw a cross section of a leaf and label the upper and lower epidermis, palisade tissue, spongy mesophyll tissue, and chloroplasts.
2. Describe the functions of the following leaf structures:
  - a) epidermis
  - b) guard cells
  - c) palisade tissue
  - d) spongy mesophyll tissue
  - e) xylem tissue
  - f) phloem tissue
3. What is the function of stomata?
4. Describe circumstances that would affect the number of stomata. Explain your answer.
5. Explain why the palisade cells are tightly compacted while the spongy mesophyll cells are more loosely organized.
6. Identify two environmental stresses that would cause stomata to close. Provide an explanation for each response.

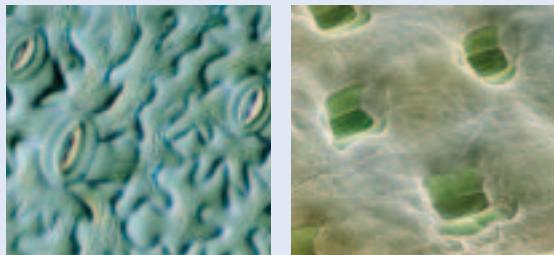
#### Applications

7. What is the advantage of having the palisade tissue directly below the upper epidermis?
8. Stomata are found mainly on the lower epidermis. Propose a reason for this.
9. In a paragraph, state the relationship between lenticels, stomata, guard cells, and the process of diffusion.
10. Greenhouse plants often have trouble surviving when placed in a natural environment. Provide a possible explanation why this is so.

#### Extensions

11. Using any materials of your choice, design and build a model that will demonstrate the workings and purpose of the stomata.
12. “Stomatal density” is the term used by scientists to refer to the number of stomata found within a certain area of the surface of a plant. In Activity C14 you determined

stomatal density in various plants. This type of analysis can provide insights into the environmental conditions in which the plant was found.



(a) Broad leaf (approx.  $\times 500$ ) (b) Needle (approx.  $\times 300$ )

- a) As you move from the foothills to the mountains deciduous trees intermingle with coniferous trees until at higher elevations the trees are primarily coniferous with needles rather than broad leaves. Needle shape is an adaptation of the leaf to climate. Needles contain less sap and are less likely to freeze. Being dark in colour and staying on the tree year-round, they can use whatever sunlight is available to the full. Using the results of Activity C14 or additional research, explain how stomatal density and needle structure also contribute to the survival of coniferous trees at higher elevations or latitudes.
- b) A scientist has proposed that elevated  $\text{CO}_2$  levels will result in decreased stomatal density while depressed  $\text{CO}_2$  levels will result in increased stomatal density. Suggest a possible controlled experimental procedure to test this hypothesis.
- c) Paleobotanists study fossil imprints of plants. In some cases the imprints provide evidence of stomatal density.
  - i) How might this data be used to suggest the environmental conditions of prehistoric times?
  - ii) How might the research of paleobotanists be used in the context of current studies of climate change?

## C 3.4 Transport in Plants

How is it possible for a plant like the tall Aspen shown in Figure C3.18 to transport the water it absorbs through its roots to the leaves in its uppermost branches so far away? This is obviously a difficult task and, one might infer, a task that must require energy input. The tree must accomplish this task, because photosynthesis occurs only in the leaves and requires water, and without photosynthesis the tree would die.

Many factors are involved in the movement of water in plants. In section C2.0, you learned about the processes of osmosis, diffusion, active transport, and transpiration. These processes result in the movement of materials through plants. Earlier on in section C3.0, you learned about the structures involved in the movement of materials through plants, such as cell membranes, vacuoles, and the vascular tissues. How do all these work together to bring about the movement of water? To answer this, you need to connect the processes and the structures—just like putting together the pieces of a jigsaw puzzle.



**FIGURE C3.18** Very tall Aspens like the ones shown here are a feature of the Alberta landscape.

### Activity C16

#### QuickLab

#### Capillary Action

The ability of the surface of a liquid to cling to the surface of a solid, causing the liquid to move along that solid, is called **capillary action**. Capillary action is at work when you place one corner of a paper towel on a spill and the liquid moves along the towel until it is completely absorbed.

#### Purpose

To demonstrate a property of water and capillary action

- Place all three capillary tubes into the beaker of food colouring. Allow them to sit for a day. Observe and record the results.
- Using the plant provided, cut the stem off close to the level of the soil. Your teacher may do this as a demonstration. Observe for a few minutes. You should begin to see water flowing out of the stem.

#### Questions

- How many drops of water were you able to get to stay on the penny? Was this number more or less than what you had expected?
- Describe what happened when dishwashing liquid was added. Do you think you would have been able to continue adding water if you had not added the dishwashing liquid?
- Compare the three capillary tubes in step 2. Which tube transported the food colouring the greatest distance?
- State a relationship between the diameter of the capillary tube and the distance of transportation.
- Explain why you were able to observe water moving out of the cut stem. Why did the water not drain back into the roots?

#### Materials and Equipment

beaker of concentrated food colouring	pennies
3 capillary tubes of same length but different diameters	liquid dish detergent
	potted herbaceous plant
	droppers
	water



#### Procedure

- Clean a penny, and using a dropper, add one drop of water at a time, very gently, to the top of the flat coin. How many drops can you get to stay on the penny: 1, 10, 100, 1000? When you think you have reached the maximum, add just one drop of liquid dish detergent. Record your results.

Take a moment to review what you know about the structures and processes that move materials in plants and the ways in which they may all be connected. Draw a diagram of a plant in your notebook showing the shoot system and the

root system. On the diagram, identify the structures involved in the transport of materials and place the processes where you think they occur. You will have an opportunity to revise your drawing later in this section.

### info **BIT**

Small insects, like the water strider, move on the surface of water because of the cohesive nature of water producing a relatively high surface tension.

## Cohesion and Adhesion

You have probably been aware since you were a small child that water is transported up the plant from the roots to the leaves. The question to consider now is, what structures and mechanisms allow the plant to pump water to the leaves, often a very great distance, against the force of gravity?

The experiments in Activity C16 appear simple, but they illustrate the complex property of water that allows water molecules to cling to each other and to other molecules. This property aids in the transport of water in plants. As you added more and more drops of water to the penny, you probably noticed that the water was forming a dome on top of the penny. Each droplet was clinging to the last one. The attraction of water molecules to other water molecules is called **cohesion**. This property is due to the polar nature of the water molecule. The slightly positive end of one water molecule attracts the slightly negative end of other water molecules with the result that the molecules tend to hold together. Each droplet that you added was attracted to the other droplets and they held together forming the dome shape. When the dishwashing liquid was added, the attraction between molecules was broken and a mini-flood was the result.

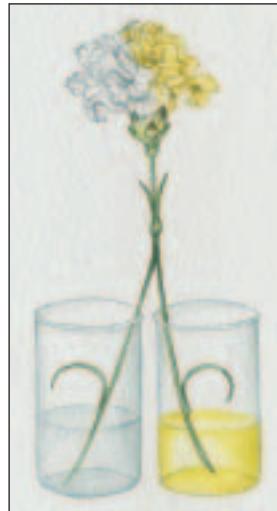
Because of their polar nature, water molecules are also attracted to molecules of other substances. In the capillary tubes, the water was able to inch up the tube partly due to cohesion, but also because the water particles were holding on to the glass sides of the tubing. Imagine rock climbers grabbing on with hands and feet to anything on the rock surface that will assist them in inching up the face of the rock. Some of the water molecules are attracted to the glass and pull themselves and other molecules up the tubing. The attraction of water molecules to molecules of other substances is called **adhesion**.

## Root Pressure

In the early morning, you may have seen droplets of water on the tips of blades of grass or at the edges of small plants like strawberries. The movement of water into these areas occurs at night when the rate of transpiration is low, but root cells are still accumulating minerals. This movement is the result of **root pressure**. In Activity C16, you would have observed water flowing from the cut stem of the plant. The fluid coming out of the stem is also due in part to root pressure, a pressure created in the xylem in the following manner. Dissolved minerals are present in the cells of the root as a result of active transport, thus producing a higher solute concentration inside the cell. Through the process of osmosis, water is drawn into the cells, creating positive pressure that forces fluid up the xylem. Water is forced from a higher pressure in the roots, toward the lower pressure in the leaves.

Examine the photos of a carnation and a celery stalk after immersion of the stems in food colouring.

1. In a short paragraph, describe what you observed in the carnation and celery stalk (Figure C3.19).
2. What are you able to infer from the results of this experiment? Explain your inference.
3. Are you able to identify any of the cells in the celery stalk cross section? Are all the cells of the stalk stained?
4. Develop a statement to explain how adhesion and cohesion are involved in moving the food colouring up the stem of the carnation and the celery stalk.



(a) A carnation



(b) A celery stalk

**FIGURE C3.19** Appearance of plant tissues after immersion in solutions of food colouring

Root pressure, while important in some plants, is not the complete explanation for water movement. It is able to push water to a maximum of only a few metres and many plants are over 100 m tall. The overall process of water movement is affected in a major way by transpiration, which has the effect of pulling water up the stem.

The properties of adhesion and cohesion are at work in moving the food colouring in the carnations and celery stalks. In growing plants, transpiration occurring at the stomata and lenticels has the additional effect of “sucking” the water up. As water is lost in the stem and leaves, it must be replaced, and so water from below is drawn up the stem as a result of transpiration. This is the reason that only certain cells, those present in the xylem, are stained in the celery stalk preparation (Figure C3.19(b)).

## From Root to Leaf: Water Transport in Plants

Earlier in this section, you drew a diagram trying to place all the pieces of the jigsaw puzzle called *transport* together. Pull out that diagram and as you work through this discussion make changes, additions, or deletions to it. See if you can create your own study guide for the flow of matter in plant systems. Keep in mind that substances (gases, minerals, sugars) must be dissolved in a film of water to be transported in plants. In addition, transport has costs for the plant in the form of energy expended in active transport across membranes, in the growth and development of vascular tissue, and in the replacement of the water lost through transpiration.

The transport of water in the plant is the result of a combination of factors. Differences in pressure are caused by osmosis and transpiration. At the root, root hairs absorb minerals from the soil by active transport. Water then enters the root hairs through osmosis because of the high concentration of solutes inside the root cells. This leads to root pressure, which forces water

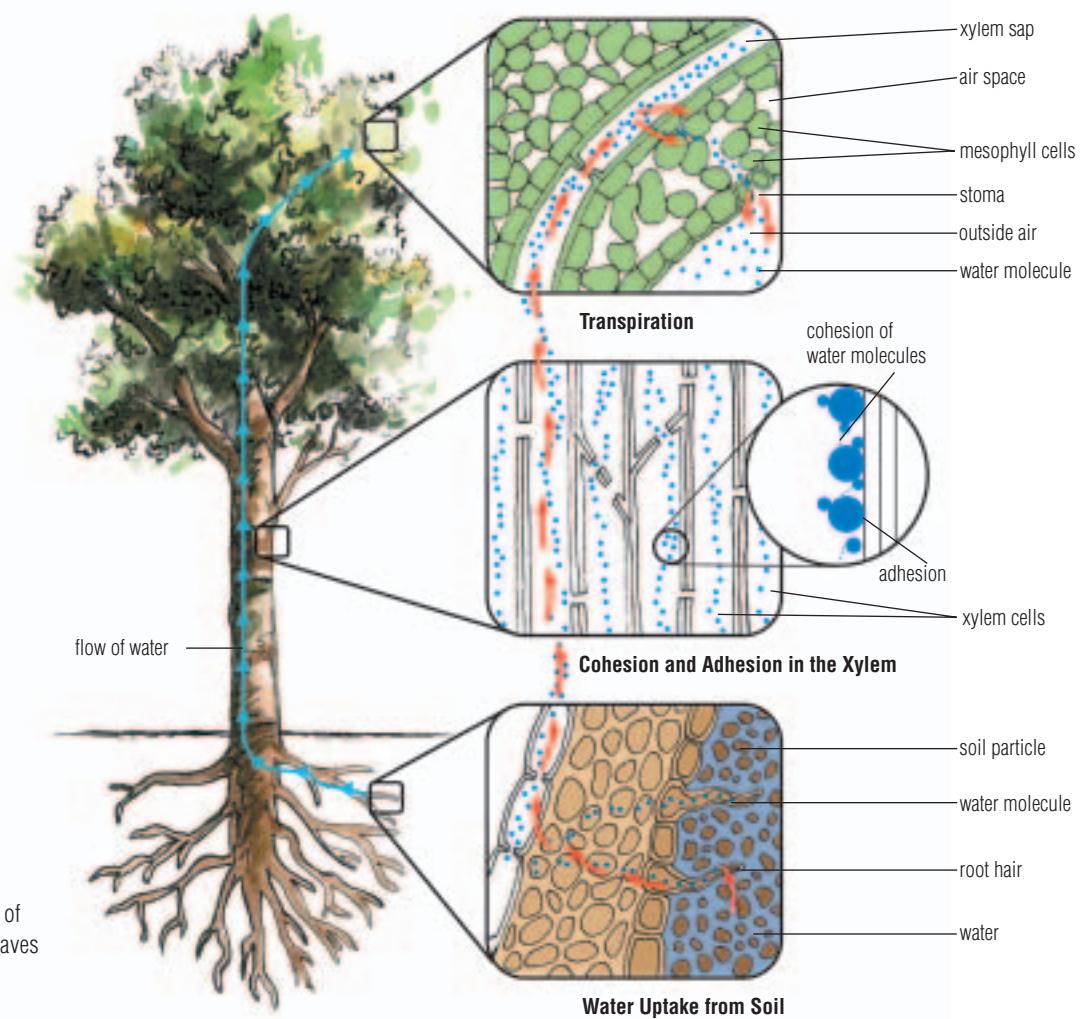
## infoBIT

The narrow column of water moving up the xylem vessels from the root to the leaf under the influence of transpiration pull is incredibly strong. The cohesion of the water molecules in the column gives it the same strength as a steel wire of the same diameter. A “pull” at the top of the column can draw water all the way from the roots.

through the cells or along cell walls into the xylem. Once the water is in the xylem tubes, it must be moved against gravity up the stem to the leaves, sometimes a distance of as much as 100 m.

The evaporation of water through the stomata and lenticels in the process of transpiration creates a **tension** or **transpiration pull**. As each water molecule evaporates into the surroundings, it creates a pull on the adjacent water molecules. Combined with the forces of adhesion and cohesion, this transpiration pull is enough to draw the water up the xylem vessels to the leaves. Once the water arrives at the leaf, the transpiration pull is enough to move the water from the xylem into the ground tissue. A high proportion of the water is lost from the plant as evaporation through the stomata. In this way, the transpiration pull is maintained to continue drawing water up the stem. Transpiration depends on temperature; if the temperature is high, the rate of evaporation through the stomata will be high and movement through the xylem will be rapid. In ideal conditions, water can rise 75 cm per minute.

The rest of the water in the leaf is used to manufacture sugars in the process of photosynthesis. These sugars in solution then move into the phloem tissue for distribution to other parts of the plant. Figure C3.20 indicates the direction of water movement, based on the pressure gradients.



**FIGURE C3.20** The flow of water from the roots to the leaves

## Required Skills

- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

## Tonicity and Plant Cells

**Tonicity** refers to the concentration of solute particles in any solution. If the environment of a cell has a higher concentration of solute particles than the cell contents, the cell environment is said to be hypertonic or to have a higher tonicity. Living cells continuously respond to the tonicity of their environment.

### The Question

What is the effect of tonicity on plant cells?

### The Hypothesis

Develop a hypothesis for the effect of increased tonicity of the environment on plant cells.



### Materials and Equipment

- compound light microscope
- Elodea canadensis* leaves or suitable alternative
- glass slides and coverslips
- droppers
- water
- concentrated salt solution

**CAUTION: Observe proper technique with the microscope to ensure safe handling of equipment. Wash your hands at the end of the lab activity.**

### Procedure

- 1 Remove a leaf from the *Elodea* plant and prepare a wet mount slide.
- 2 On low power, focus on an area of cells near the leaf's edge. Find an area in which you can clearly identify the following cell structures: cell wall, nucleus, chloroplasts, and vacuoles. The cytoplasm is colourless, so it is not directly visible. Switch to a higher power objective lens to see all of the cell structures.
- 3 Draw a diagram of your field of view. Calculate the size of a single *Elodea* cell using the procedure from Activity C2. Label the cell structures on your diagram and include total magnification and actual size.

- 4 Continue to observe the slide for a few more minutes and record observations that relate to moving materials around the cell or into and out of the cell.
- 5 Place a drop of concentrated salt solution at one end of the coverslip. With a paper towel at the opposite end of the coverslip, slowly draw the salt solution under the coverslip as you would if you were staining the cells. In this way, you will change the tonicity of the environment of the cells.
- 6 Carefully observe the slide for any changes in the cell structures. Pay particular attention to the vacuoles. Adjust the light to maximize the contrast between cell structures. Vacuoles may be difficult to distinguish, as they are transparent and full of water when the cell is turgid. Record your observations.

### Analyzing and Interpreting

1. What movement did you notice inside the cells in step 4? Explain what was causing the movement.
2. State a relationship between the length of time taken to make the observation in step 4 and the amount of movement inside the cell. What variable is responsible for the relationship you have stated?
3. How was the tonicity of the environment changed in step 5?
4. What did you observe in steps 5 and 6? What happened to the cell?

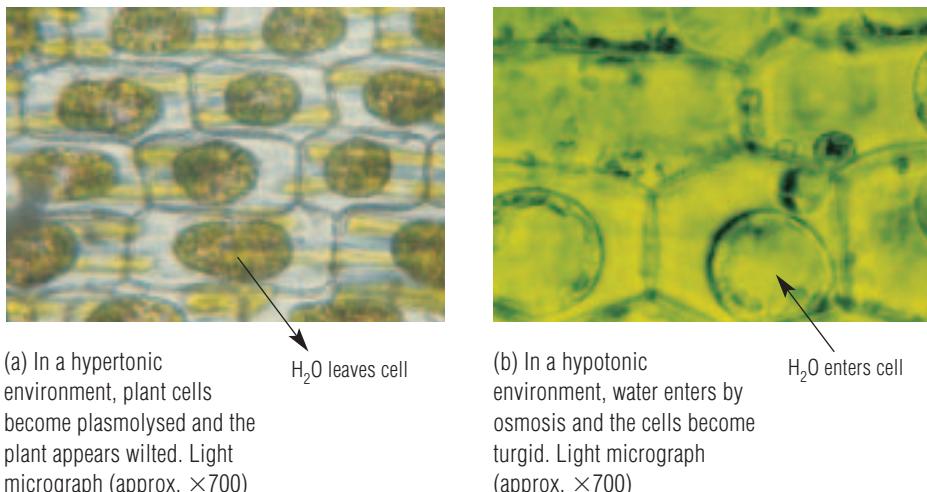
### Forming Conclusions

5. Based on your knowledge of cell structures and the mechanisms involved in transport, state which of the structures and mechanisms respond to an increase in the tonicity of the cell's surroundings. Support your statement with evidence from the experiment.

### Applying and Connecting

6. Use a water balloon as a model to explain what happens to the central vacuole as it gains and loses water.

**FIGURE C3.21** Differences in the salt concentration of the environment affect structures in plant cells.



## The Effect of Tonicity on Plant Cells

Changes in the tonicity of the environment have an effect on osmosis and on the arrangement of structures in plant cells. You will be able to observe these effects if you place some plant cells, for instance, an *Elodea* leaf, in a concentrated salt solution. The higher solute concentration on the outside of the cell causes water to pass by osmosis from the cell into the surroundings. The effect on the cell is called **plasmolysis**. The water contained inside the vacuole leaves the vacuole and the cell, with the result that the vacuole appears shrunken. Imagine the appearance of a water balloon if you slowly let out the water. As the vacuole shrinks, the cell contents begin to pull away from the cell wall. The cell membrane may become visible because it is no longer pushed up against the cell wall. The result of plasmolysis of the cells is a leaf that is wilted or limp, because it is no longer being held out by the pressure of fluid against the walls of each individual cell.

If the leaf is returned to fresh water, the water will re-enter the cell by osmosis, with the result that the vacuole swells, and the internal pressure increases until the vacuole cannot increase in size. At this point, the cell is said to be turgid. Water can continue to pass in and out of the vacuole but there is no net increase in volume. Turgidity is important to plants because the pressure in all of the cells combines to hold the green parts of the plant up to the sunlight. This allows the chloroplasts to trap light energy. Maintaining turgidity or pressure within cells allows the plant to hold itself up. For this reason, it is beneficial for plant cells to be in a hypotonic environment. Figure C3.21 shows the effects of hypertonic and hypotonic environments on plant cells.

## From Source to Sink: Sugar Transport in Plants

If you were to remove a ring of phloem tissue from the stem of a plant, the plant would die because the cells would not be receiving the products of photosynthesis where they are needed. If phloem cells are killed, through dehydration or excessive heat for instance, the movement of sugars stops. The mechanism of phloem transport is a critical process for multicellular plants. It takes the products of photosynthesis from the place where they are

manufactured, the leaves, also called the **source**, to the places where they will be used or stored, called the **sink**.

Recall the structure of the phloem tissue discussed on page 300. Sieve tube cells are cylindrical cells that lack nuclei and have perforated sides and end walls that allow the cytoplasm to stream between cells. These sieve tube cells depend on the companion cells for many functions, including the movement of sugars into and out of the sieve tube cells.

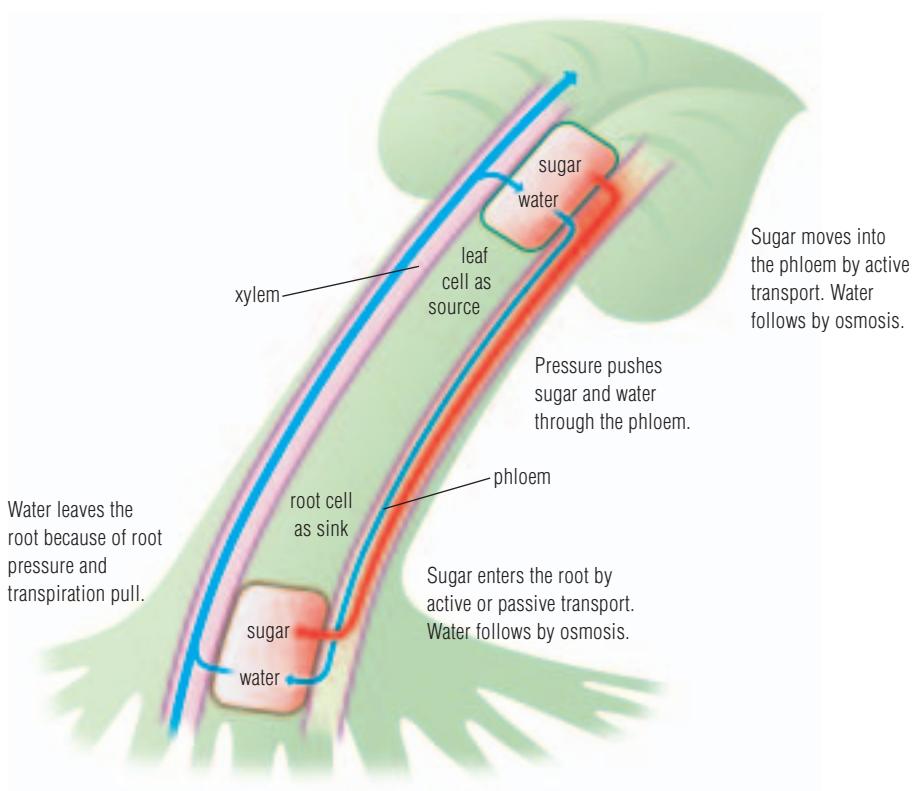
At the leaf, that is, the source, the phloem becomes loaded as companion cells use carrier proteins and active transport to take in sugar molecules from the sites of photosynthesis. Water then moves into the cells by osmosis. In turn, the water moves into the sieve cells. The increased water pressure inside the sieve cells pushes the water and sugars through the phloem to the rest of the plant. Imagine increasing the pressure inside a hose. As the pressure builds, the water is forced through the hose until it finds a place to escape. In the case of phloem transport, the end is a sink, which may be a root, a tuber, or another part of the plant such as a fruit. This description of moving materials through the phloem is called the **pressure-flow theory**.

Sugars are actively transported across cell membranes from the sieve tube cells into adjacent cells. The sugar molecules may be used in growth, respiration, or other life processes, for example, at the growing tips (meristems). Sugars may also be stored in the roots, stems, or leaves. As the sugars leave the sieve tube cells, water also moves out into surrounding cells. The water may increase the turgidity of the surrounding cells, or leave the plant through transpiration, or move into the xylem tissue for transport through the plant. As the water pressure in the sieve tube is decreased at the sink, more water and sugar is pushed into these cells from the cells above. The **pressure differences** produced by active transport and osmosis maintain a constant flow of food down the sieve tube, as shown in Figure C3.22.

## reSEARCH

The companion cells are thought to support the living sieve tube cells. Find out how the interaction of these cells makes phloem transport possible. Begin your search at

 [www.pearsoned.ca/school/science10](http://www.pearsoned.ca/school/science10)



**FIGURE C3.22** Movement of sugar and water through the phloem and xylem. Arrows show the direction of movement.

# Design a Lab

## Required Skills

- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

## Environmental Conditions and Water Movement

Environmental conditions that cause an increased rate of water loss from the plant will have an impact on the movement of water.

### The Question

How do environmental conditions affect the movement of water in plants?

### Design and Conduct Your Investigation

- 1 Make a list of variables that you think may affect the amount of water lost from the plant and therefore the movement of water in the plant.
- 2 For each variable on your list, write a hypothesis to predict how changing that variable will affect movement of water in the plant.

- 3 Choose one of the variables on your list. Plan and write the procedure for an investigation to test your hypothesis. Outline the steps of your investigation, including safety precautions, and identify the variables that you will control and those that will be manipulated.
- 4 List all the materials and equipment you will need to carry out your investigation.
- 5 Submit your lab design to your teacher. Once your teacher has approved your design, perform the investigation.
- 6 Analyze your results. Do your data support your hypothesis?
- 7 Compare your experimental design with the designs and procedures used by your classmates. How might you adapt or improve upon your design?
- 8 Identify any new questions that arose from your experiment and that you would like to explore.

### C3.4 Check and Reflect

#### Knowledge

1. What are the properties of water that aid in water transport in plants?
2. Explain how the vacuoles of a plant cell are affected when the cell is placed in a hypertonic solution and in a hypotonic solution.
3. Water loss could be a danger to the survival of the plant. Explain the control mechanisms the plant uses to reduce water loss.
4. What are the two types of plant vascular tissues? What is the function of each?
5. Suggest a role for turgidity in photosynthesis.
6. Refer to the Minds-On Activity on page 317. Explain why only certain of the cells were dyed by the food colouring.

7. Describe the processes involved in the movement of water from the roots to the leaves.
8. Explain how sugars from photosynthesis are transported from the leaves to other parts of a plant.

#### Application

9. Create a concept map showing the relationships between the following structures and processes involved in the transport of materials and gas exchange in plants: roots, root hairs, root epidermis, xylem, phloem, stomata, ground tissue, transpiration.

## C 3.5 Control Systems

### infoBIT

Animals have both instinctive and learned behaviours that allow them to respond to internal and external stimuli. If you touch something hot, you pull your hand away. In the presence of a loud noise, you cover your ears. You and other animals respond to changes in your environment as well as to signs from your body. When you react to these signals in some way, you are responding to the **stimuli**. The way in which you react is based on the type and direction of the stimulus. If you are hungry and you smell pizza, you will most likely follow your nose to the food.

Plants are not as obviously responsive as animals but they do have definite responses to specific stimuli. Think about the needs of a plant and the changes in a plant's surroundings that would require it to respond. The plant needs to be able to carry out photosynthesis and therefore requires water, carbon dioxide, and light. Plants grow toward the light. This growth movement is a response of the plant to the stimulus of light and is called **phototropism**. "Photo" means light and "tropism" refers to the movement of the plant in response to the stimulus. Stems exhibit **positive phototropism**, meaning that they grow toward light. Roots show a weak **negative phototropism** because they grow away from the light.

You may be less aware of another external stimulus to which growing plants respond. Observe the photo in Figure C3.23 showing a germinating bean seed. You will notice that growth is occurring in two directions. The shoot system is growing up toward the light, and the root system is growing down away from the light. There is another factor at play—gravity. Plants respond to Earth's gravitational force through growth movement as well. This is called **gravitropism**. Stems grow against the gravitational force and so show **negative gravitropism** while roots grow toward the gravitational force and so show **positive gravitropism**. An older term for gravitropism is **geotropism**. The responses to these factors are summarized in Table C3.1 below.

Over time, a houseplant kept in one location will show signs of growing toward the light. To avoid having the plant grow entirely in one direction, it is necessary to move the plant occasionally, either to a new location or simply to rotate it.



**FIGURE C3.23** A germinating bean seed showing the opposite directions of the growth of the shoot and root

**TABLE C3.1** Responses of Plant Parts to Stimuli

Plant Part	Stimulus	Tropism
stem	light	positive phototropism
root	light	weak negative phototropism
stem	gravity	negative gravitropism
root	gravity	positive gravitropism

The observed growth responses to light and gravity are most probably due to the plant's attempt to meet its needs. Roots growing away from the light and in the same direction as gravity are more likely to find soil, water, and minerals. Stems growing toward the light and against gravity will receive the energy required by the chloroplasts in their leaves for the photosynthesis reaction. Tropisms are important **control systems** to ensure survival of the plant.

## Required Skills

- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

## Investigating Gravitropism and Phototropism

### The Questions

1. What evidence is there to indicate that roots respond to gravity?
2. Which part of the stem is responsible for producing a positive phototropic response?

### The Hypothesis

1. Read Procedure Part 1 and propose a method to determine that gravity, and not some other variable, is responsible for the growth of roots downward.
2. Based on your observations, propose the location in the plant where the phototropic response is initiated.



### Materials and Equipment

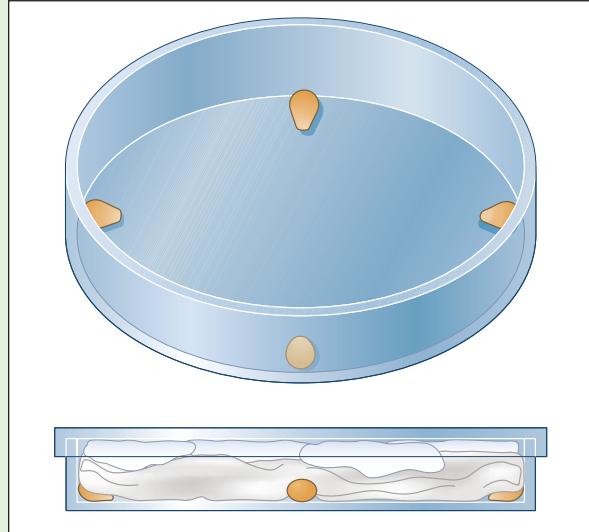
- oat seeds
- corn seeds (pre-soaked for 48 hours)
- planting tray
- potting soil
- light source
- Petri dishes
- paper towel
- cotton batting
- aluminium foil
- grease pencil
- gloves

### Part 1

#### Procedure

1. Imagine the Petri dish as the face of a clock. Mark four positions on the underside of the Petri dish at 12:00, 3:00, 6:00, and 9:00 positions.

2. Place corn seeds at the marked positions in the Petri dish, narrow side facing into the centre of the dish. Try to keep the seeds positioned this way throughout the set-up. See Figure C3.24.
3. Place a wet paper towel on top of the seeds.
4. Add cotton batting on top of the paper towel so that when you place the lid on the Petri dish, the seed and paper towel do not move.
5. Close the lid on the Petri dish and seal the dish with tape.
6. With the seeds facing out, tape the dish to the inside of a closet or cupboard door that will be in complete darkness.
7. Leave the Petri dish untouched for several days in the dark.
8. Observe the germination of the seeds and record your observations.



**FIGURE C3.24** Placement of corn seeds for steps 2–5.

## Analyzing and Interpreting

1. Draw a diagram to show the corn seed germination. Label what you believe to be the shoot and the root.

## Forming Conclusions

2. Make a statement relating the germination response of the seed to gravity. Include an explanation of how you can be sure that what you observed is not a phototropic response.

## Part 2

### Procedure

- 1 Fill the planting tray with potting soil. Scatter oat seeds into the tray and cover them lightly with soil.
- 2 Keep the tray in a location so that only one side of the tray is facing the light source.
- 3 Keep watering the oats lightly and allow the oats to grow 2–3 cm above the soil.
- 4 Transplant approximately one-third of the oat seedlings to a deeper pot and cover them with soil, exposing only their tips.
- 5 Keep the deeper pot of covered seedlings in the original setting relative to the light source.
- 6 Cover the tips of another third of the oat seedlings in the tray with aluminium foil. Make sure that only the tips are covered, not any of the parts below the tips. Leave these in the tray in its original setting.
- 7 Allow the remaining third of the seedlings to remain untouched in the tray in its original setting.
- 8 Allow the seedlings to grow for several days, watering them and making observations daily.
- 9 Carefully observe the growth of the oat seedlings in the three conditions and record your observations.

## Analyzing and Interpreting

1. Draw a diagram of your observations.
2. Use a chart similar to the one below to record your explanations of the observations. Remember to give your chart a title.

Growth Condition	Observation of Tropism	Explanation for the Observation
control group		
seedlings covered in soil exposing only the tip		
seedlings' tips covered with aluminium foil		

## Forming Conclusions

3. Where is phototropic response initiated in the seedlings?

## Extending

4. This activity is similar to one that Charles and Francis Darwin conducted. They concluded that the phototropic stimulus was detected by the tip of the plant, but that the actual growth response of bending was carried out at another location. Do your data support their conclusion? Explain.

## reSEARCH

Find out about the experiments conducted in space to test the effects of phototropism and gravitropism. Begin your search at



[www.pearsoned.ca/  
school/science10](http://www.pearsoned.ca/school/science10)

## Investigations of Phototropism

Positive phototropism is easy to observe but more difficult to explain. The series of investigations that revealed the mechanism of phototropism are classic examples of scientific inquiry, in which observations lead to questions and questions lead to controlled experiments. The scientists who formulated the questions and conducted the experiments were:

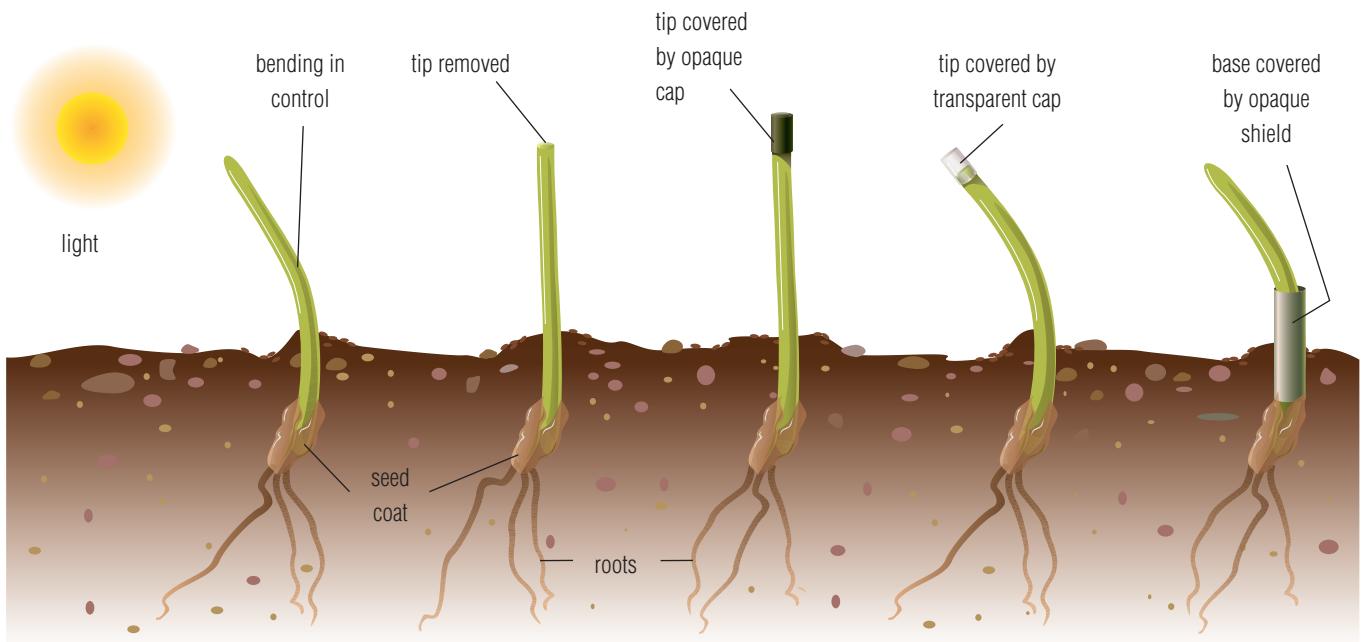
- Charles Darwin and his son Francis, who asked in 1880: *Which part of the plant detects and responds to the phototropic stimulus?*
- Peter Boysen-Jensen, who asked in 1913: *What is the signal that initiates the phototropic response?*
- F. W. Went, who asked in 1926: *What is the specific substance responsible for initiating the phototropic response?*

All these scientists focussed their experiments on a particular part of the shoot system in the developing seedling of the oat plant, *Avena sativa*, and various other grasses. The outer sheath of an oat or grass seedling covers the developing leaves. The shoot grows as a result of the lengthening of the cells of this outer sheath. Once the shoot reaches 4–6 cm, the sheath stops growing and the enclosed stem and leaves split through and continue growing. If light comes from one direction only, the seedlings will show phototropism by bending of the sheath toward the light source. The Darwins, Boysen-Jensen, and Went conducted their experiments during the growth period when the outer sheath lengthens rapidly.

The experiment that you performed in Part 2 of Activity C19, in which you used oat seedlings under different conditions of growth, was very similar to the one performed by Charles and Francis Darwin. Figure C3.25 shows their results. They found that the seedlings with the tips covered did not respond to light, and so they were able to conclude that the tip of the stem was the area responsible for the detection of the light stimulus, but it was not the place where the response was carried out. The plants with everything except the tips buried still showed a growth response toward the light. The Darwins inferred that the cells of the tip were somehow communicating with the cells in the area of the bending. Charles Darwin documented their findings in his publication, *The Power of Movement in Plants*.

By 1913, Peter Boysen-Jensen, a Dutch plant physiologist, was trying to determine how the tip was communicating with the area of elongation. The **area of elongation** was lower on the leaf and facing away from the light source. It was called the area of elongation because the phototropic response was created by the elongation of cells on the side of the leaf facing away from the light, causing the leaf to bend toward the light as demonstrated in Figure C3.26.

Boysen-Jensen snipped off the tip of the grass seedlings, covered the stump with gelatin, and replaced the tip. Phototropism continued normally. The gelatin had not interfered with the plant's detection of the stimulus, nor with the growth response. He then tried the same procedure using a thin slice of the mineral mica instead of the gelatin. Phototropism was not observed in this experiment.



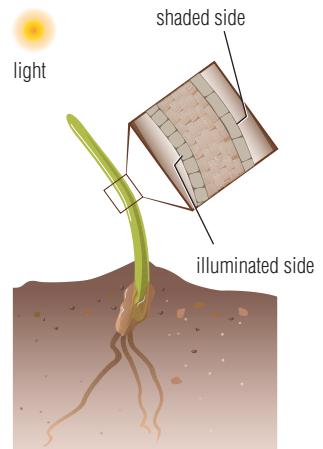
**FIGURE C3.25** Stages in the Darwins' experiment on phototropism

Boysen-Jensen concluded that whatever was responsible for communicating stimulus information from the tip to the area of elongation was able to diffuse through the gelatin, but not through the mica. He suggested that the growth response could only be accomplished as a result of a chemical moving from the tip to the area of elongation.

In 1926, a graduate student in Holland, F. W. Went, was able to isolate this chemical substance. It was later given the name **auxin**. Since then, analysis of the chemical substance has indicated that the auxin is a **hormone**, a chemical compound that is manufactured in one area and transported to another location where, in low concentrations, it has the ability to initiate a physiological response—in this case, cell elongation. Other plant hormones have been isolated since Went's discovery and are used in horticulture.

## The Mechanism of Gravitropism

How does a root know to grow toward the gravitational force? If a plant gets knocked over, how do the roots know which way is down? Scientists believe that plants rely on heavy starch particles in specialized cells as indicators of gravity. If a plant is tipped, the starch grains shift and settle in a new location due to gravity. Think of a jar partially filled with jellybeans. As long as the jar is standing upright, the jellybeans are at the bottom. What happens if the jar is knocked over? The jellybeans shift and settle on the new bottom. When the starch grains do this in the root cells, it is thought that the movement is detected by the plant, and a growth response results. This hypothesis received considerable support from microgravity studies in space shuttle experiments.



**FIGURE C3.26** The effect of changes in cells in the area of elongation on the bending of the plant toward the light

## SEARCH

Investigate the plant hormones that have been described since the discovery of auxin. Begin your search at

 [www.pearsoned.ca/  
school/science10](http://www.pearsoned.ca/school/science10)

## SEARCH

Using the data from *PlantWatch* and any additional information you can find on a plant of your choice, compile and organize data on flowering time. Analyze the data based on variables that might influence flowering time. Begin your search at

 [www.pearsoned.ca/  
school/science10](http://www.pearsoned.ca/school/science10)

## Other Control Mechanisms

Other tropic responses apart from phototropism and gravitropism have been identified in plants. The tendrils of a pea plant that come in contact with a chain-link fence will attach to it and so receive support as the plant grows upward. This is a response to touch. Plants also respond to temperature, chemicals, and water.

To reproduce, the plant must flower and produce seeds. The flowering of plants at particular times of the year is often in response to the length of darkness the plant is exposed to. This is another control mechanism. Some plants require long nights (more than 12 hours of darkness) to produce flowers. Examples include chrysanthemums, poinsettias, and Christmas cactus. Other plants require more than 12 hours of light to flower. These include coneflowers, lettuce, spinach, and potatoes. Some plants will flower regardless of the length of dark and light periods, if they have all of their other needs met. These plants include tomatoes, strawberries, and corn.

Some scientists believe that climate change is affecting the blooming of plant species. By tracking bloom times in different locales over many years, it may be possible to determine if there are links between climate changes and plant responses. The Alberta Wildflower Survey was started in 1987 and has expanded to become *PlantWatch*, organized through the University of Alberta Devonian Botanic Gardens. The program, coordinated by University of Alberta research scientist Elizabeth Beaubien, includes amateur scientists in the work of tracking bloom times of common plants. To participate, you must adhere to recording and reporting protocols established by the program. Such protocols are important to the process of scientific inquiry because they set the rules of the study and ensure accurate data collection.

### C3.5 Check and Reflect

#### Knowledge

1. Define tropism in your own words.
2. Explain what is meant by the terms “positive phototropism” and “negative gravitropism.”
3. What are the benefits of phototropism and gravitropism for plants?
4. Explain the results of Charles and Francis Darwin’s work. How did their observations further the study of plant physiology?
5. Describe how the work of Boysen-Jensen is an example of scientific inquiry.

#### Applications

6. Explain the statement: *Tropisms are the plant’s control mechanisms.*
7. Why was it important in your experiment with the corn seeds to ensure that the seeds were not exposed to light?

#### Extensions

8. Plant physiologists are able to produce synthetic plant hormones. Suggest possible purposes for these chemical compounds. Use print or electronic media to research your answer.
9. Create a list of plants with different light requirements for flowering that grow in your area.
10. Imagine that you are making the rules or protocol for data collection and reporting for *PlantWatch*. Create a format for the compilation of data that will be useful in determining whether bloom dates are changing over time for particular species of plants found in Alberta. Compare and discuss your format with a classmate. After your discussion, is there anything you would change to improve the data collection?



Dr. Olga Kovalchuk

# Dr. Olga Kovalchuk— Biotechnology Research Scientist

Plants are not able to move away from conditions that threaten their survival. A single plant cannot adapt to changes in its environment, but over time, a species can adapt to survive. Dr. Olga Kovalchuk studies genetic adaptation of plants to environmental stress. Her research at the University of Lethbridge focusses on environmental pollutants such as ionizing and UV-B radiation, heavy metals, and toxic chemicals, and their potentially damaging effect on DNA.

Dr. Kovalchuk has an M.D. degree and received her Ph.D. from the Ukrainian Genetics and Hygiene Research Centre in Kiev. Her Ph.D. research involved development and testing of plant-based systems to monitor genetic effects of radioactive contamination. These systems were later called “biological Geiger counters” because they were able to provide information on the levels and effects of radiation. With researchers at the Chernobyl Research Centre, Dr. Kovalchuk showed that certain communities of plant species are adapted for survival in radioactively contaminated soil. One of her long-term goals is to find the molecular mechanisms that allow these plants to adapt and survive.

Combining her interests in genetics and medicine, Dr. Kovalchuk is conducting the first-ever detailed study to compare cellular responses to varying and sustained doses of radiation and is involved in research to find new approaches to the use of radiation therapy in the treatment of cancer. In her investigations, she works in collaboration with other scientists. She shares her passion for science with her husband, Dr. Igor Kovalchuk, whose research focusses on how a plant responds to attack from bacteria or viruses. World centres of biotechnology and cancer research are interested in their collaborative research at the University of Lethbridge.

Dr. Kovalchuk’s message to students is, “The more you know, the more doors will be opened to you in your life. Currently, there are exciting opportunities for young scientists in all areas of research. Get involved and you may contribute to developing hardier crops, feeding the poor, fighting climate change, or finding a cure for cancer. This is very challenging and satisfying work. By encouraging young people to become involved in research, we will ensure Canadian leadership in many scientific fields. Let’s be the first!”

1. Why is the ability to work on a team important for a research scientist?
2. What part of Dr. Kovalchuk’s research is most interesting to you? What else would you like to know?
3. Identify a question, problem, or issue related to plants, that you would like to research.